

**Los Alamos  
National Laboratory**

## Passive Neutron Coincidence Counters

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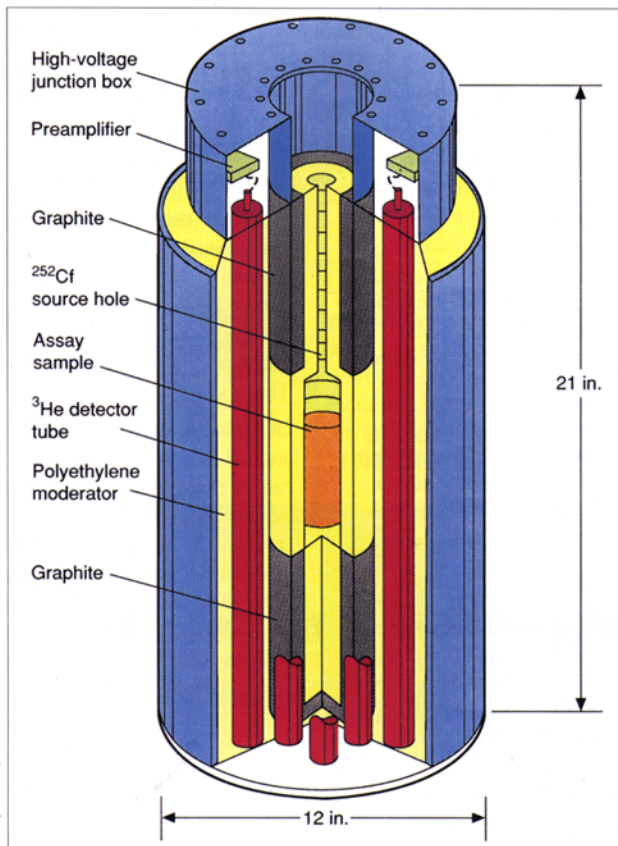
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*Fig. 1. Inventory Sample Counter Mod III. The inventory sample counter shown at left is designed to measure small samples (light orange). Neutrons from the sample are slowed by the polyethylene (yellow) and detected by the  $^3\text{He}$  tubes (red). The tubes send signals to the preamplifiers (green) in the high-voltage junction box (blue); the signals are then sent to a computer for processing. The graphite (black) improves the uniformity of the neutron detection efficiency throughout the sample cavity.*

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**P**assive neutron coincidence counters (NCCs) assay nuclear materials that contain spontaneously fissioning isotopes; the assays are based on coincident neutrons that are naturally emitted by these materials. NCCs are well suited for measuring dense materials containing  $^{238}\text{Pu}$ ,  $^{240}\text{Pu}$ , and  $^{242}\text{Pu}$ . These materials are often in the form of fuel plates and pins, powder, pellets, scrap, and waste. NCCs are also suitable for mixtures of uranium and plutonium oxide and kilogram quantities of  $^{238}\text{U}$ . NCCs work well in areas with a high neutron background because background neutrons are not coincident. Coincidence counters have been designed to measure samples ranging in size from a fraction of a liter to 200 liters.

The Inventory Sample Counter Mod III shown above is one example of the general class of passive neutron coincidence counters developed by the Safeguards Assay Group at Los Alamos National Laboratory.

## NCC Operating Principles

The design of the NCC is determined by the items to be measured and the operating environment. (See Fig. 2 for a basic design.) In general, neutrons to be detected are slowed by about 10 cm of polyethylene and then captured and counted by  $^3\text{He}$  tubes embedded in the polyethylene. The number of  $^3\text{He}$  tubes and their placement in the polyethylene determines the neutron detection efficiency. High efficiency is important for coincidence counting. Therefore, it is customary for the detectors to surround the sample ( $4\pi$ -geometry).

The electronic pulses produced by neutrons captured in the  $^3\text{He}$  tubes are amplified and shaped in fast, hybrid preamplifier circuits, then the pulses are sent to the coincidence circuit for processing. The coincidence-counting electronics package contains a high-voltage power supply for the  $^3\text{He}$  tubes, a low-voltage power supply for the preamplifiers, a coincidence circuit, and a computer interface. This package is compact and portable; it can also be rack mounted. The counting circuits determine the total count rate and the coincidence count rate. The computer then analyzes the raw data and applies electronic dead-time corrections and background subtractions before the mass of nuclear material is calculated.

Ideally, the detector parameters, the coincidence count rate, and the isotopic composition determine the plutonium content of each sample. In practice, two main effects must be taken into account for accurate assays: neutron multiplication and changes in the neutron detection efficiency. Neutron multiplication occurs when neutrons from the sample induce additional fissions in the sample; the induced fissions increase the coincidence count rate. Alpha particles from plutonium can react with impurities in assay samples and produce neutrons; multiplication of these neutrons can also bias the assays. The neutron detection efficiency is changed by materials that slow

or absorb neutrons in the sample cavity of the detector. Water and plastic, which slow neutrons, and boron, which captures neutrons, are common examples of such materials.

Some techniques presently available to deal with neutron multiplication and efficiency changes are to (1) construct nonlinear calibration curves that represent the material to be assayed, (2) calculate the correction factors for induced fissions (for pure samples or samples with fixed geometry and density), (3) correct for changes in neutron detection efficiency using count rate ratios from two groups of  $^3\text{He}$  tubes (for samples with low absorption), (4) combine results of active and passive measurements of the same sample, (5) measure the neutron multiplication using special neutron multiplicity counting electronics, and (6) use a  $^{252}\text{Cf}$  add-a-source technique to correct for material dependence.

To reduce the self-multiplication in large samples, a cadmium-lined sample cavity absorbs low-energy neutrons returning from the polyethylene. If there are significant numbers of background neutrons from process lines or nearby storage areas, an external shield of polyethylene and cadmium may be added around the polyethylene containing the  $^3\text{He}$  tubes.

DOE facilities use neutron coincidence counters both at-line and off-line. Unsealed process materials inside glove boxes can be assayed by extending a well down from the glove box floor and surrounding the well with a neutron counter. A free-standing, off-line counter can assay canned, sealed plutonium samples near the glove box or in a separate room. If an NCC must be moved regularly, its mass can be reduced by eliminating the external shield, reducing the mass of polyethylene, and shortening the  $^3\text{He}$  tubes at the expense of both efficiency and immunity to background neutrons.

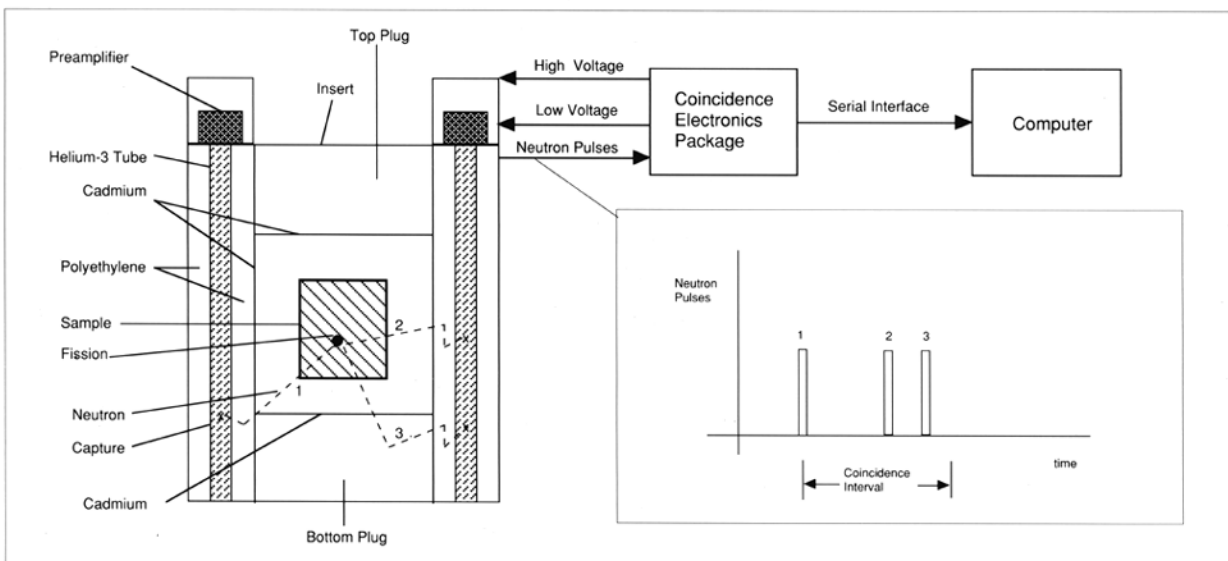


Fig. 2. Schematic of the basic NCC design. Fission neutrons must pass through polyethylene before being detected, thus their energies are moderated to lower values at which  $^3\text{He}$  tubes are more efficient. Extra material at the top and bottom of the canister helps the detector efficiency depend less on axial sample position. The coincidence electronics processes pulses from the tubes; the instrument computer analyzes the raw data. In this example, three neutrons (labelled 1, 2, and 3) from a single fission event are detected within the coincidence interval and produce coincidence counts.

## Measurement Performance

The precision and accuracy of NCCs for plutonium measurements vary widely with the type of material assayed. Table I shows typical performance values for a variety of plutonium process materials. The detector sensitivity is typically a few milligrams of  $^{240}\text{Pu}$ .

## Selecting and Procuring an NCC

In many cases an existing NCC design may be suitable. Some existing NCCs are listed in Table II on page 4. If an existing coincidence counter design provides all the desired features, it may already be available from a commercial vendor. Much of the technology required to fabricate and test neutron coincidence counters has been transferred from Los Alamos to private industry; several companies now supply such instruments. Commercial suppliers include Canberra Industries, Inc./Jomar Systems Division, Los Alamos, New Mexico 87544 (505-662-9811) and National Nuclear Corporation, Mountain View, California 94043 (415-962-9220).

The Los Alamos Safeguards Assay Group develops the technology to measure neutrons from nuclear materials in a variety of forms and geometries. Figure 3 suggests the range of sizes in which the counters can be constructed. Field prototypes can be developed and constructed by Los Alamos when commercial NCCs are not suitable. Los Alamos can also

Table I. Typical Precisions and Accuracies of NCCs (5-min. measurements)

Plutonium Material	Precision (%)	Expected In-Plant Accuracy (%)
Pure oxide	0.5	1-2
Impure oxide	0.5	1-5
Metal	0.3	1-5
Mixed oxide	0.5	1-3
Direct oxide reduction salt cake	0.5	5
Electrorefining metal input	0.3	5-10
Scrub from molten salt extraction	5	5-20
PuF <sub>4</sub>	2-5	10-50
Scrap	1-3	5-25
Waste	2-10	5-100

participate in acceptance testing, develop new data evaluation algorithms, calibrate instruments, and help with software integration, documentation, and training. Software is available for assay, calibration, and measurement control. NCC procurement costs vary with the counter size, number of  $^3\text{He}$  tubes, and the level of custom design effort.



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Fig. 3. Passive neutron coincidence counters are made in a variety of sizes but use the same coincidence electronics. The photo at right is a portable high-level neutron coincidence counter. The photo at left is a much larger counter designed to assay waste in 200-l drums. Los Alamos Fellow Howard Menlove prepares to assay a waste drum. Neutron detectors are in the door, in the top and bottom, and in the three fixed sides of the counter. This counter incorporates the  $^{252}\text{Cf}$  add-a-source technique.

Table II. Applications of Neutron Coincidence Counters

Counter Name	Where used	Application
Passive/active well counter	Los Alamos Plutonium Facility	Bulk plutonium assay
Feed coincidence counter	Savannah River	Receipts verification
Waste coincidence counter	Savannah River	Waste assay
Flat-squared counter	Los Alamos Plutonium Facility	Bulk plutonium assay
In-line counter	Los Alamos Plutonium Facility	Waste assay
Drum counter	Los Alamos/Savannah River	Scrap and waste assay
Counter for 5-gal. pails	Savannah River	Scrap and waste assay
Horizontal in-line counter	Los Alamos Plutonium Facility	Bulk plutonium assay
Vertical in-line counter	Los Alamos Plutonium Facility	Bulk plutonium assay
Moisture correction counter	Los Alamos Plutonium Facility	Wet sample assay
Confirmatory measurements counter	Major DOE sites	Receipts verification
Dual range coincidence counter	Rocky Flats	Low- and high-mass assay
<sup>238</sup> Pu heat-source counter	Los Alamos Plutonium Facility	Heat-source quality assurance
HLNC- II	Worldwide	General plutonium assay
Inventory sample counter	Worldwide	Very small sample assay
Universal fast breeder reactor counter	Worldwide	Fuel assembly verification
Capsule counter	Japan	Capsule verification
Pin-tray counter	Japan	Fuel pin verification
Birdcage counter	Japan	Fuel plate verification
Canister counter	Japan	Bulk MOX assay
Plutonium nitrate bottle counter	Los Alamos Plutonium Facility	Solution assay
Material accountancy glovebox counter	Japan	In-line MOX verification
Holdup slab counter	Japan	Glove box MOX verification

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